1. Introduction

This report presents estimates by the United States government of U.S. anthropogenic greenhouse gas emissions and sinks for the years 1990 through 2001. A summary of these estimates is provided in Table 1-8 and Table 1-9 by gas and source category. The emission estimates in these tables are presented on both a full molecular mass basis and on a Global Warming Potential (GWP) weighted basis in order to show the relative contribution of each gas to global average radiative forcing.[1] This report also discusses the methods and data used to calculate these emission estimates.

In June of 1992, the United States signed, and later ratified in October, the United Nations Framework Convention on Climate Change (UNFCCC). The objective of the UNFCCC is "to achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food prdocution is not threatened and to enable economic development to proceed in a sustainable manner." [2, 3]

Parties to the Convention, by ratifying, committed "to develop, periodically update, publish and make available…national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies…"[4] The United States views this report as an opportunity to fulfill this commitment under the UNFCCC.

In 1988, preceding the creation of the UNFCCC, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC). The charter of the IPCC is to assess available scientific information on climate change, assess the environmental and socio-economic impacts of climate change, and formulate response strategies (IPCC 1996). Under Working Group 1 of the IPCC, nearly 140 scientists and national experts from more than thirty countries collaborated in the creation of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) to ensure that the emission inventories submitted to the UNFCCC are consistent and comparable between nations. The IPCC accepted the *Revised 1996 IPCC Guidelines* at its Twelfth Session (Mexico City, 11-13 September 1996). This report presents information in accordance with these guidelines. In addition, this inventory is in accordance with the recently published IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, which further expanded upon the methodologies in the *Revised 1996 IPCC Guidelines.*

Overall, this inventory of anthropogenic greenhouse gas emissions (1) provides a basis for the ongoing development of methodologies for estimating sources and sinks of greenhouse gases; (2) provides a common and consistent mechanism through which Parties to the UNFCCC can estimate emissions and compare the relative contribution of individual sources, gases, and nations to climate change; and (3) is a prerequisite for accounting for reductions and evaluating possible mitigation strategies.

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[1] See the section below entitled *Global Warming Potentials* for an explanation of GWP values.

[2] The term "anthropogenic," in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

[3] Article 2 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change. See <http://unfccc.int>. (UNEP/WMO 2000)

[4] Article 4 of the Framework Convention on Climate Change published by the UNEP/WMO Information Unit on Climate Change (also identified in Article 12). See <http://unfccc.int>. (UNEP/WMO 2000)

Greenhouse Gases

Although the Earth's atmosphere consists mainly of oxygen and nitrogen, neither plays a significant role in enhancing the greenhouse effect because both are essentially transparent to terrestrial radiation. The greenhouse effect is primarily a function of the concentration of water vapor, carbon dioxide (CO_2), and other trace gases in the atmosphere that absorb the terrestrial radiation leaving the surface of the Earth (IPCC 1996). Changes in the atmospheric concentrations of these greenhouse gases can alter the balance of energy transfers between the atmosphere, space, land, and the oceans.[5] A gauge of these changes is called radiative forcing, which is a simple measure of changes in the energy available to the Earth-atmosphere system (IPCC 1996). Holding everything else constant, increases in greenhouse gas concentrations in the atmosphere will produce positive radiative forcing (i.e., a net increase in the absorption of energy by the Earth).

Climate change can be driven by changes in the atmospheric concentrations of a number of radiatively active gases and aerosols. We have clear evidence that human activities have affected concentrations, distributions and life cycles of these gases (IPCC 1996).

Naturally occurring greenhouse gases include water vapor, CO_2, methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Several classes of halogenated substances that contain fluorine, chlorine, or bromine are also greenhouse gases, but they are, for the most part, solely a product of industrial activities. Chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) are halocarbons that contain chlorine, while halocarbons that contain bromine are referred to as bromofluorocarbons (i.e., halons). As stratospheric ozone depleting substances, CFCs, HCFCs, and halons are covered under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. The UNFCCC defers to this earlier international treaty. Consequently, Parties are not required to include these gases in national greenhouse gas inventories.[6] Some other fluorine containing halogenated substances—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)—do not deplete stratospheric ozone but are potent greenhouse gases. These latter substances are addressed by the UNFCCC and accounted for in national greenhouse gas inventories.

There are also several gases that, although they do not have a commonly agreed upon direct radiative forcing effect, do influence the global radiation budget. These tropospheric gases include carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and tropospheric (ground level) ozone (O_3). Tropospheric ozone is formed by two precursor pollutants, volatile organic compounds (VOCs) and nitrogen oxides (NO_x) in the presence of ultraviolet light (sunlight). Aerosols are extremely small particles or liquid droplets that are often composed of sulfur compounds, carbonaceous combustion products, crustal materials and other human induced pollutants. They can affect the absorptive characteristics of the atmosphere. Comparatively, however, the level of scientific understanding of aerosols is still very low. (IPCC 2001)

Carbon dioxide, CH_4, and N_2O are continuously emitted to and removed from the atmosphere by natural processes on Earth. Anthropogenic activities, however, can cause additional quantities of these and other greenhouse gases to be emitted or sequestered, thereby changing their global average atmospheric concentrations. Natural activities such as respiration by plants or animals and seasonal cycles of plant growth and decay are examples of processes that only cycle carbon or nitrogen between the atmosphere and organic biomass. Such processes, except when directly or indirectly perturbed out of equilibrium by anthropogenic activities, generally do not alter average atmospheric greenhouse gas concentrations over decadal timeframes. Climatic changes resulting from anthropogenic activities, however, could have positive or negative feedback effects on these natural systems. Atmospheric concentrations of these gases, along with their rates of growth and atmospheric lifetimes, are presented in Table 1-1.

[5] For more on the science of climate change, see NRC (2001).

[6] Emissions estimates of CFCs, HCFCs, halons and other ozone-depleting substances are included in this document for informational purposes.

Table 1-1: Global atmospheric concentration (ppm unless otherwise specified), rate of concentration change (ppb/year) and atmospheric lifetime (years) of selected greenhouse gases

Atmospheric Variable	CO_2	CH_4	N_2O	SF_6[a]	CF_4[a]
Pre-industrial atmospheric concentration	280	0.722	0.270	0	40
Atmospheric concentration[b]	370.3	1.842	0.316	4.7	80
Rate of concentration change[c]	1.5[d]	0.007[d]	0.0008	0.24	1.0
Atmospheric Lifetime	50-200[c]	12[f]	114[f]	3,200	>50,000

Source: Current atmospheric concentrations for CO_2, CH_4, N_2O, and SF_6 are from Blasing and Jones (2002). All other data is from IPCC (2001).

[a] Concentrations in parts per trillion (ppt) and rate of concentration change in ppt/year.

[b] Concentration for CO_2 was measured in 2001. Concentrations for all other gases were measured in 2000.

[c] Rate is calculated over the period 1990 to 1999.

[d] Rate has fluctuated between 0.9 and 2.8 ppm per year for CO_2 and between 0 and 0.013 ppm per year for CH_4 over the period 1990 to 1999.

[e] No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.

[f] This lifetime has been defined as an “adjustment time” that takes into account the indirect effect of the gas on its own residence time.

A brief description of each greenhouse gas, its sources, and its role in the atmosphere is given below. The following section then explains the concept of Global Warming Potentials (GWPs), which are assigned to individual gases as a measure of their relative average global radiative forcing effect.

Water Vapor (H_2O). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapor. Water vapor is neither long-lived nor well mixed in the atmosphere, varying spatially from 0 to 2 percent (IPCC 1996). In addition, atmospheric water can exist in several physical states including gaseous, liquid, and solid. Human activities are not believed to affect directly the average global concentration of water vapor, but, the radiative forcing produced by the increased concentrations of other greenhouse gases may indirectly affect the hydrologic cycle. While a warmer atmosphere has an increased water holding capacity, increased concentrations of water vapor affects the formation of clouds, which can both absorb and reflect solar and terrestrial radiation. Aircraft contrails, which consist of water vapor and other aircraft emittants, are similar to clouds in their radiative forcing effects (IPCC 1999).

Carbon Dioxide (CO_2). In nature, carbon is cycled between various atmospheric, oceanic, land biotic, marine biotic, and mineral reservoirs. The largest fluxes occur between the atmosphere and terrestrial biota, and between the atmosphere and surface water of the oceans. In the atmosphere, carbon predominantly exists in its oxidized form as CO_2. Atmospheric CO_2 is part of this global carbon cycle, and therefore its fate is a complex function of geochemical and biological processes. Carbon dioxide concentrations in the atmosphere increased from approximately 280 parts per million by volume (ppmv) in pre-industrial times to 370.3 ppmv in 2001, a 32 percent increase (IPCC 2001 and Blasing and Jones 2002).[7, 8] The IPCC definitively states that “the present atmospheric CO_2 increase is caused by anthropogenic emissions of CO_2” (IPCC 2001). Forest clearing, other biomass burning, and some non-energy production processes (e.g., cement production) also emit notable quantities of CO_2.

In its second assessment, the IPCC also stated that “[t]he increased amount of carbon dioxide [in the atmosphere] is leading to climate change and will produce, on average, a global warming of the Earth’s surface because of its enhanced greenhouse effect—although the magnitude and significance of the effects are not fully resolved” (IPCC 1996).

Methane (CH_4). Methane is primarily produced through anaerobic decomposition of organic matter in biological systems. Agricultural processes such as wetland rice cultivation, enteric fermentation in animals, and the decomposition of animal wastes emit CH_4, as does the decomposition of municipal solid wastes. Methane is also emitted during the production and distribution of natural gas and petroleum, and is released as a by-product of coal mining and incomplete fossil fuel combustion. Atmospheric concentrations of CH_4 have increased by about 150 percent since pre-industrial times, although the rate of increase has been declining. The IPCC has estimated that slightly more

[7] The pre-industrial period is considered as the time preceding the year 1750 (IPCC 2001).

[8] Carbon dioxide concentrations during the last 1,000 years of the pre-industrial period (i.e., 750-1750), a time of relative climate stability, fluctuated by about ±10 ppmv around 280 ppmv (IPCC 2001).

than half of the current CH_4 flux to the atmosphere is anthropogenic, from human activities such as agriculture, fossil fuel use and waste disposal (IPCC 2001).

Methane is removed from the atmosphere through a reaction with the hydroxyl radical (OH) and is ultimately converted to CO_2. Minor removal processes also include reaction with chlorine in the marine boundary layer, a soil sink, and stratospheric reactions. Increasing emissions of CH_4 reduce the concentration of OH, a feedback that may increase the atmospheric lifetime of CH_4 (IPCC 2001).

Nitrous Oxide (N_2O). Anthropogenic sources of N_2O emissions include agricultural soils, especially production of nitrogen-fixing crops and forages, the use of synthetic and manure fertilizers, and manure deposition by livestock; fossil fuel combustion, especially from mobile combustion; adipic (nylon) and nitric acid production; wastewater treatment and waste combustion; and biomass burning. The atmospheric concentration of N_2O has increased by 16 percent since 1750, from a pre industrial value of about 270 ppb to 316 ppb in 2000, a concentration that has not been exceeded during the last thousand years. Nitrous oxide is primarily removed from the atmosphere by the photolytic action of sunlight in the stratosphere.

Ozone (O_3). Ozone is present in both the upper stratosphere,[9] where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere,[10] where it is the main component of anthropogenic photochemical "smog." During the last two decades, emissions of anthropogenic chlorine and bromine-containing halocarbons, such as chlorofluorocarbons (CFCs), have depleted stratospheric ozone concentrations. This loss of ozone in the stratosphere has resulted in negative radiative forcing, representing an indirect effect of anthropogenic emissions of chlorine and bromine compounds (IPCC 1996). The depletion of stratospheric ozone and its radiative forcing was expected to reach a maximum in about 2000 before starting to recover, with detection of such recovery not expected to occur much before 2010 (IPCC 2001).

The past increase in tropospheric ozone, which is also a greenhouse gas, is estimated to provide the third largest increase in direct radiative forcing since the pre-industrial era, behind CO_2 and CH_4. Tropospheric ozone is produced from complex chemical reactions of volatile organic compounds mixing with nitrogen oxides (NO_x) in the presence of sunlight. Ozone, carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate matter are included in the category referred to as "criteria pollutants" in the United States under the Clean Air Act[11] and its subsequent amendments. The tropospheric concentrations of ozone and these other pollutants are short-lived and, therefore, spatially variable.

Halocarbons, Perfluorocarbons, and Sulfur Hexafluoride (SF_6). Halocarbons are, for the most part, man-made chemicals that have both direct and indirect radiative forcing effects. Halocarbons that contain chlorine (chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), methyl chloroform, and carbon tetrachloride) and bromine (halons, methyl bromide, and hydrobro-mofluorocarbons (HBFCs)) result in stratospheric ozone depletion and are therefore controlled under the *Montreal Protocol on Substances that Deplete the Ozone Layer*. Although CFCs and HCFCs include potent global warming gases, their net radiative forcing effect on the atmosphere is reduced because they cause stratospheric ozone depletion, which is itself an important greenhouse gas in addition to shielding the Earth from harmful levels of ultraviolet radiation. Under the *Montreal Protocol*, the United States phased out the production and importation of halons by 1994 and of CFCs by 1996. Under the Copenhagen Amendments to the *Protocol*, a cap was placed on the production and importation of HCFCs by non-Article 5[12] countries beginning in 1996, and then followed by a complete phase-out by the year 2030. While ozone depleting gases

[9] The stratosphere is the layer from the troposphere up to roughly 50 kilometers. In the lower regions the temperature is nearly constant but in the upper layer the temperature increases rapidly because of sunlight absorption by the ozone layer. The ozone-layer is the part of the stratosphere from 19 kilometers up to 48 kilometers where the concentration of ozone reaches up to 10 parts per million.

[10] The troposphere is the layer from the ground up to 11 kilometers near the poles and up to 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere where people live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for most weather processes, including most of the water vapor and clouds.

[11] [42 U.S.C § 7408, CAA § 108]

[12] Article 5 of the *Montreal Protocol* covers several groups of countries, especially developing countries, with low consumption rates of ozone depleting substances. Developing countries with per capita consumption of less than 0.3 kg of certain ozone depleting substances (weighted by their ozone depleting potential) receive financial assistance and a grace period of ten additional years in the phase-out of ozone depleting substances.

covered under the *Montreal Protocol* and its Amendments are not covered by the UNFCCC, they are reported in this inventory under Annex T for informational purposes.

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are not ozone depleting substances, and therefore are not covered under the *Montreal Protocol*. They are, however, powerful greenhouse gases. HFCs are primarily used as replacements for ozone depleting substances but also emitted as a by-product of the HCFC-22 manufacturing process. Currently, they have a small aggregate radiative forcing impact, but it is anticipated that their contribution to overall radiative forcing will increase (IPCC 2001). PFCs and SF_6 are predominantly emitted from various industrial processes including aluminum smelting, semiconductor manufacturing, electric power transmission and distribution, and magnesium casting. Currently, the radiative forcing impact of PFCs and SF_6 is also small, but they have a significant growth rate, extremely long atmospheric lifetimes, and are strong absorbers of infrared radiation, and therefore have the potential to influence climate far into the future (IPCC 2001).

Carbon Monoxide (CO). Carbon monoxide has an indirect radiative forcing effect by elevating concentrations of CH_4 and tropospheric ozone through chemical reactions with other atmospheric constituents (e.g., the hydroxyl radical, OH) that would otherwise assist in destroying CH_4 and tropospheric ozone. Carbon monoxide is created when carbon-containing fuels are burned incompletely. Through natural processes in the atmosphere, it is eventually oxidized to CO_2. Carbon monoxide concentrations are both short-lived in the atmosphere and spatially variable.

Nitrogen Oxides (NO_x). The primary climate change effects of nitrogen oxides (i.e., NO and NO_2) are indirect and result from their role in promoting the formation of ozone in the troposphere and, to a lesser degree, lower stratosphere, where it has positive radiative forcing effects.[13] Additionally, NO_x emissions from aircraft are also likely to decrease CH_4 concentrations, thus having a negative radiative forcing effect (IPCC 1999). Nitrogen oxides are created from lightning, soil microbial activity, biomass burning (both natural and anthropogenic fires) fuel combustion, and, in the stratosphere, from the photo-degradation of N_2O. Concentrations of NO_x are both relatively short-lived in the atmosphere and spatially variable.

Nonmethane Volatile Organic Compounds (NMVOCs). Nonmethane volatile organic compounds include substances such as propane, butane, and ethane. These compounds participate, along with NO_x, in the formation of tropospheric ozone and other photochemical oxidants. NMVOCs are emitted primarily from transportation and industrial processes, as well as biomass burning and non-industrial consumption of organic solvents. Concentrations of NMVOCs tend to be both short-lived in the atmosphere and spatially variable.

Aerosols. Aerosols are extremely small particles or liquid droplets found in the atmosphere. They can be produced by natural events such as dust storms and volcanic activity, or by anthropogenic processes such as fuel combustion and biomass burning. They affect radiative forcing in both direct and indirect ways: directly by scattering and absorbing solar and thermal infrared radiation; and indirectly by increasing droplet counts that modify the formation, precipitation efficiency, and radiative properties of clouds. Aerosols are removed from the atmosphere relatively rapidly by precipitation. Because aerosols generally have short atmospheric lifetimes, and have concentrations and compositions that vary regionally, spatially, and temporally, their contributions to radiative forcing are difficult to quantify (IPCC 2001).

The indirect radiative forcing from aerosols are typically divided into two effects. The first effect involves decreased droplet size and increased droplet concentration resulting from an increase in airborne aerosols. The second effect involves an increase in the water content and lifetime of clouds due to the effect of reduced droplet size on precipitation efficiency (IPCC 2001). Recent research has placed a greater focus on the second indirect radiative forcing effect of aerosols.

Various categories of aerosols exist, including naturally produced aerosols such as soil dust, sea salt, biogenic aerosols, sulfates, and volcanic aerosols, and anthropogenically manufactured aerosols such as industrial dust and carbonaceous[14] aerosols (e.g., black carbon, organic carbon) from transportation, coal combustion, cement manufacturing, waste incineration, and biomass burning.

[13] NO_x emissions injected higher in the stratosphere, primarily from fuel combustion emissions from high altitude supersonic aircraft, can lead to stratospheric ozone depletion.

[14] Carbonaceous aerosols are aerosols that are comprised mainly of organic substances and forms of black carbon (or soot) (IPCC 2001).

Table 1-2: Global Warming Potentials and Atmospheric Lifetimes (Years) Used in This Report

Gas	Atmospheric Lifetime	GWP[a]
Carbon dioxide (CO_2)	50-200	1
Methane (CH_4)[b]	12±3	21
Nitrous oxide (N_2O)	120	310
HFC-23	264	11,700
HFC-32	5.6	650
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF_4	50,000	6,500
C_2F_6	10,000	9,200
C_4F_{10}	2,600	7,000
C_6F_{14}	3,200	7,400
SF_6	3,200	23,900

Source: (IPCC 1996)
[a] 100 year time horizon
[b] The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

The net effect of aerosols on radiative forcing is believed to be negative (i.e., net cooling effect on the climate), although because they remain in the atmosphere for only days to weeks, their concentrations respond rapidly to changes in emissions.[15] Locally, the negative radiative forcing effects of aerosols can offset the positive forcing of greenhouse gases (IPCC 1996). "However, the aerosol effects do not cancel the global-scale effects of the much longer-lived greenhouse gases, and significant climate changes can still result" (IPCC 1996).

The IPCC's Third Assessment Report notes that "the indirect radiative effect of aerosols is now understood to also encompass effects on ice and mixed-phase clouds, but the magnitude of any such indirect effect is not known, although it is likely to be positive" (IPCC 2001). Additionally, current research suggests that another constituent of aerosols, elemental carbon, may have a positive radiative forcing (Jacobson 2001). The primary anthropogenic emission sources of elemental carbon include diesel exhaust, coal combustion, and biomass burning.

Global Warming Potentials

A Global Warming Potential (GWP) is intended as a quantified measure of the globally averaged relative radiative forcing impacts of a particular greenhouse gas (see Table 1-2). It is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Direct radiative effects occur when the gas itself influences other radiatively important processes such as the atmospheric lifetimes of other gases. The reference gas used is CO_2, and therefore GWP weighted emissions are measured in teragrams of CO_2 equivalents (Tg CO_2 Eq.)[16] The relationship between gigagrams (Gg) of a gas and Tg CO_2 Eq. can be expressed as follows:

$$\text{Tg } CO_2 \text{ Eq} = (\text{Gg of gas}) \times (\text{GWP}) \times \left(\frac{\text{Tg}}{1{,}000\,\text{Gg}}\right)$$

where,

Tg CO_2 Eq. = Teragrams of Carbon Dioxide Equivalents

Gg = Gigagrams (equivalent to a thousand metric tons)

GWP = Global Warming Potential

Tg = Teragrams

GWP values allow for a comparison of the impacts of emissions and reductions of different gases. According to the IPCC, GWPs typically have an uncertainty of ±35 percent. The parties to the UNFCCC have also agreed to use GWPs based upon a 100 year time horizon although other time horizon values are available.

"...consistent with decision 2/CP.3, Annex I Parties should report aggregate emissions and removals of greenhouse gases, expressed in CO_2 equivalent terms at summary inventory level, using GWP values provided by the IPCC in its Second Assessment Report, … based on the effects of greenhouse gases over a 100-year time horizon."[17]

[15] Volcanic activity can inject significant quantities of aerosol producing sulfur dioxide and other sulfur compounds into the stratosphere, which can result in a longer negative forcing effect (i.e., a few years) (IPCC 1996).

[16] Carbon comprises 12/44[ths] of carbon dioxide by weight.

[17] Framework Convention on Climate Change; <http://unfccc.int/cop8/latest/5_sbstal5add1.pdf>; 1 November 2002; Report of the Conference of the Parties at its eighth session; held at New Delhi from 23 October to 1 November 2002; Addendum; Part One: Action taken by the Conference of the Parties at its eighth session; Decision -/CP.8; Communications from Parties included in Annex I to the Convention: Guidelines for the Preparation of National Communications by Parties Included in Annex I to the Convention, Part 1: UNFCCC reporting guidelines on annual inventories; p. 6. Advance unedited version. FCCC (2002)

Box 1-1: The IPCC Third Assessment Report and Global Warming Potentials

The IPCC recently published its Third Assessment Report (TAR), providing the most current and comprehensive scientific assessment of climate change. Within this report, the GWPs of several gases were revised relative to the IPCC's Second Assessment Report (SAR), and new GWPs have been calculated for an expanded set of gases. Since the SAR, the IPCC has applied an improved calculation of CO_2 radiative forcing and an improved CO_2 response function (presented in WMO 1999). The GWPs are drawn from WMO (1999) and the SAR, with updates for those cases where significantly different new laboratory or radiative transfer results have been published. Additionally, the atmospheric lifetimes of some gases have been recalculated. Because the revised radiative forcing of CO_2 is about 12 percent lower than that in the SAR, the GWPs of the other gases relative to CO_2 tend to be larger, taking into account revisions in lifetimes. In addition, the values for radiative forcing and lifetimes have been calculated for a variety of halocarbons, which were not presented in the SAR. Table 1-3 presents the new GWPs, relative to those presented in the SAR.

Table 1-3: Comparison of 100 Year GWPs

Gas	SAR	TAR	Change	
Carbon dioxide (CO_2)	1	1	NC	NC
Methane (CH_4)*	21	23	2	10%
Nitrous oxide (N_2O)	310	296	(14)	(5%)
HFC-23	11,700	12,000	300	3%
HFC-32	650	550	(100)	(15%)
HFC-125	2,800	3,400	600	21%
HFC-134a	1,300	1,300	NC	NC
HFC-143a	3,800	4,300	500	13%
HFC-152a	140	120	(20)	(14%)
HFC-227ea	2,900	3,500	600	21%
HFC-236fa	6,300	9,400	3,100	49%
HFC-4310mee	1,300	1,500	200	15%
CF_4	6,500	5,700	(800)	(12%)
C_2F_6	9,200	11,900	2,700	29%
C_4F_{10}	7,000	8,600	1,600	23%
C_6F_{14}	7,400	9,000	1,600	22%
SF_6	23,900	22,200	(1,700)	(7%)

Source: (IPCC 2001)
NC (No Change)
* The GWP of CH_4 includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Although the GWPs have been updated by the IPCC, this report uses GWPs from the Second Assessment Report. The UNFCCC reporting guidelines for national inventories[18] were updated in 2002 but continue to require the use of GWPs from the SAR so that current estimates of aggregate greenhouse gas emissions for 1990 through 2001 are consistent and comparable with estimates developed prior to the publication of the TAR. Therefore, to comply with international reporting standards under the UNFCCC, official emission estimates are reported by the United States using SAR GWP values. For informational purposes, emission estimates that use the updated GWPs are presented below and in even more detail in Annex S. Overall, these revisions to GWP values do not have a significant effect on U.S. emission trends, as shown in Table 1-4. All estimates provided throughout this report are also presented in unweighted units.

Table 1-4: Effects on U.S. Greenhouse Gas Emission Trends Using IPCC SAR and TAR GWP Values (Tg CO_2 Eq.)

	Change from 1990 to 2001		Revisions to Annual Estimates	
Gas	SAR	TAR	1990	2001
CO_2	791.1	791.1	0	0
CH_4	(38.12)	(41.75)	61.3	57.7
N_2O	27.0	25.8	(18.0)	(19.2)
HFCs, PFCs, and SF_6	16.6	10.0	(2.6)	(9.2)
Total	**796.6**	**785.1**	**40.8**	**29.3**
Percent Change	**13.0%**	**12.7%**	**0.7%**	**0.4%**

[18] See <http://unfccc.int/cop8/latest/5_sbstal5add1.pdf>.

Table 1-5 below shows a comparison of total emissions estimates by sector using both the IPCC SAR and TAR GWP values. For most sectors, the change in emissions was minimal. The effect on emissions from waste was by far the greatest (8.7 percent), due the predominance of CH_4 emissions in this sector. Emissions from all other sectors were comprised of mainly CO_2 or a mix of gases, which moderated the effect of the changes.

Table 1-5: Comparison of Emissions by Sector using IPCC SAR and TAR GWP Values (Tg CO_2 Eq.)

Sector	1990	1995	1996	1997	1998	1999	2000	2001
Energy								
SAR GWP (Used In Inventory)	5,147.5	5,481.6	5,661.4	5,733.0	5,749.4	5,809.5	6,010.4	5,927.1
TAR GWP	5,168.4	5,500.9	5,680.3	5,751.5	5,767.6	5,826.9	6,027.7	5,944.1
Difference (%)	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Industrial Processes								
SAR GWP (Used In Inventory)	302.2	308.3	318.8	321.4	325.9	313.7	312.6	287.6
TAR GWP	298.1	302.3	310.0	312.8	317.5	304.5	302.9	277.3
Difference (%)	(1.4%)	(1.9%)	(2.8%)	(2.7%)	(2.6%)	(2.9%)	(3.1%)	(3.6%)
Agriculture								
SAR GWP (Used In Inventory)	441.0	468.4	473.7	479.0	481.3	479.3	475.1	474.9
TAR GWP	443.1	470.8	475.2	480.3	482.7	480.8	476.4	476.2
Difference (%)	0.5%	0.5%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Land-Use Change and Forestry								
SAR GWP (Used In Inventory)	(1,072.8)	(1,064.2)	(1,061.0)	(840.6)	(830.5)	(841.1)	(834.6)	(838.1)
TAR GWP	(1,072.8)	(1,064.2)	(1,061.0)	(840.6)	(830.5)	(841.1)	(834.6)	(838.1)
Difference (%)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Waste								
SAR GWP (Used In Inventory)	248.9	256.6	253.1	249.2	244.7	247.0	249.2	246.6
TAR GWP	270.8	279.1	275.2	270.9	266.0	268.4	270.8	267.9
Difference (%)	8.8%	8.8%	8.7%	8.7%	8.7%	8.7%	8.7%	8.7%
Net Emissions (Sources and Sinks)								
SAR GWP (Used In Inventory)	**5,066.8**	**5,450.7**	**5,646.0**	**5,942.0**	**5,970.9**	**6,008.5**	**6,212.7**	**6,098.1**
TAR GWP	**5,107.6**	**5,488.9**	**5,679.6**	**5,974.9**	**6,003.3**	**6,039.6**	**6,243.2**	**6,127.4**
Difference (%)	**0.8%**	**0.7%**	**0.6%**	**0.6%**	**0.5%**	**0.5%**	**0.5%**	**0.5%**

NC (No change)
Note: Totals may not sum due to independent rounding.

Greenhouse gases with relatively long atmospheric lifetimes (e.g., CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) tend to be evenly distributed throughout the atmosphere, and consequently global average concentrations can be determined. The short-lived gases such as water vapor, carbon monoxide, tropospheric ozone, ozone precursors (e.g., NO_x, and NMVOCs), and tropospheric aerosols (e.g., SO_2 products and carbonaceous particles), however, vary regionally, and consequently it is difficult to quantify their global radiative forcing impacts. No GWP values are attributed to these gases that are short-lived and spatially inhomogeneous in the atmosphere.

Recent Trends in U.S. Greenhouse Gas Emissions

In 2001, total U.S. greenhouse gas emissions were 6,936.2 teragrams of CO_2 equivalents (Tg CO_2 Eq.)[19] (13.0 percent above 1990 emissions). Emissions declined for the second time since 1990, decreasing by 1.6 percent (111.2 Tg CO_2 Eq.) from 2000 to 2001, primarily because of a decrease in CO_2 emissions from fossil fuel combustion. The reduction in fossil fuel combustion emissions is linked to the following factors: 1) slowing of economic growth in 2001, 2) a considerable

[19] Estimates are presented in units of teragrams of carbon dioxide equivalents (Tg CO_2 Eq.), which weight each gas by its Global Warming Potential, or GWP, value. (See section on Global Warming Potentials, Chapter 1.)

Figure 1-1

U.S. GHG Emissions by Gas

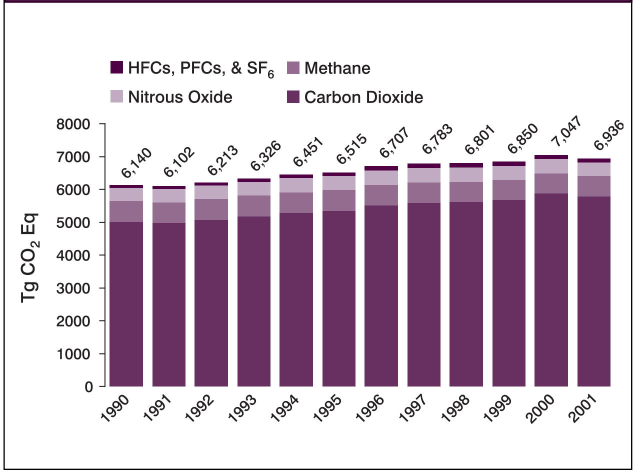


Figure 1-2

Annual Percent Change in U.S. GHG Emissions

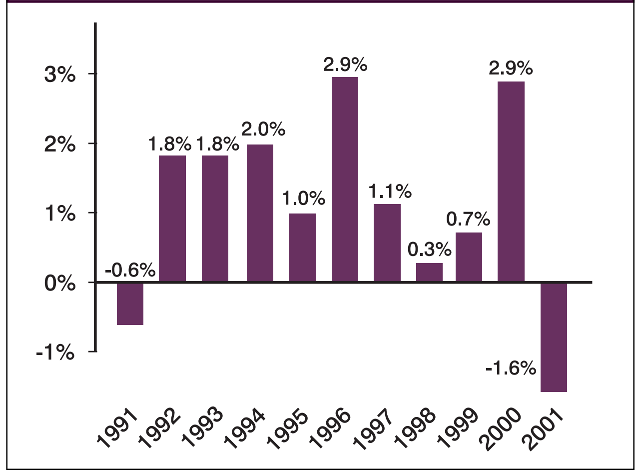
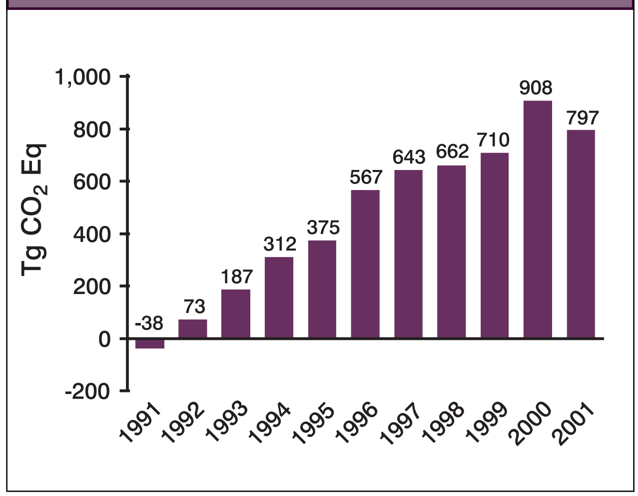


Figure 1-3

Absolute Change in U.S. GHG Emissions Since 1990



reduction in industrial output, leading to decreased demand for electricity and fuel, 3) warmer winter conditions compared to 2000, and 4) an increased share of output from nuclear facilities. (See the following section for an analysis of emission trends by general economic sectors). Figure 1-1 through Figure 1-3 illustrate the overall trends in total U.S. emissions by gas, annual changes, and absolute changes since 1990.

As the largest source of U.S. greenhouse gas emissions, CO_2 from fossil fuel combustion accounted for a nearly constant 80 percent of global warming potential (GWP) weighted emissions in the 1990s. Emissions from this source category grew by 17 percent (800.1 Tg CO_2 Eq.) from 1990 to 2001 and were responsible for most of the increase in national emissions during this period. The recent annual change in CO_2 emissions from fossil fuel combustion was a reduction of 77.3 Tg CO_2 Eq. (1.4 percent), which is the second decrease in emissions since the Inventory base year 1990, the first being in 1991. The source's average annual growth rate was 1.3 percent from 1990 through 2001. Historically, changes in emissions from fossil fuel combustion have been the dominant factor affecting U.S. emission trends.

Changes in CO_2 emissions from fossil fuel combustion are influenced by many long-term and short-term factors, including population and economic growth, energy price fluctuations, technological changes, and seasonal temperatures. On an annual basis, the overall consumption of fossil fuels in the United States generally fluctuates in response to changes in general economic conditions, energy prices, weather, and the availability of non-fossil alternatives. For example, in a year with increased consumption of goods and services, low fuel prices, severe summer and winter weather conditions, nuclear plant closures, and lower precipitation feeding hydroelectric dams, there would likely be proportionally greater fossil fuel consumption than a year with poor economic performance, high fuel prices, mild temperatures, and increased output from nuclear and hydroelectric plants.

In the longer-term, energy consumption patterns respond to changes that affect the scale of consumption (e.g., population, number of cars, and size of houses), the efficiency with which energy is used in equipment (e.g., cars, power plants, steel mills, and light bulbs) and consumer behavior (e.g., walking, bicycling, or telecommuting to work instead of driving).

Table 1-6: Annual Change in CO_2 Emissions from Fossil Fuel Combustion for Selected Fuels and Sectors (Tg CO_2 Eq. and Percent)

Sector	Fuel Type	1996 to 1997		1997 to 1998		1998 to 1999		1999 to 2000		2000 to 2001	
Electricity Generation	Coal	44.1	3%	30.6	2%	8.7	0%	89.4	5%	(50.1)	(3%)
Electricity Generation	Natural Gas	13.9	7%	29.1	13%	12.0	5%	20.6	8%	4.3	2%
Electricity Generation	Petroleum	9.0	14%	29.7	40%	(7.6)	(7%)	(5.7)	(6%)	10.7	12%
Transportation[a]	Petroleum	7.3	0%	33.0	2%	58.7	4%	49.8	3%	19.7	1%
Residential	Natural Gas	(14.0)	(3%)	(23.7)	(9%)	10.0	9%	13.9	3%	(9.6)	(1%)
Commercial	Natural Gas	3.1	2%	(10.8)	(6%)	1.7	1%	9.1	5%	1.6	1%
Industrial	Coal	1.2	1%	(8.7)	(6%)	(6.1)	(4%)	2.3	2%	(7.7)	(6%)
Industrial	Natural Gas	1.1	0%	(11.7)	(2%)	(17.6)	(4%)	12.5	3%	(33.5)	(7%)
All Sectors[b]	**All Fuels[b]**	**74.2**	**1%**	**20.5**	**0%**	**68.3**	**1%**	**202.8**	**4%**	**(77.9)**	**(1%)**

[a] Excludes emissions from International Bunker Fuels.
[b] Includes fuels and sectors not shown in table.

Energy-related CO_2 emissions also depend on the type of fuel or energy consumed and its carbon intensity. Producing a unit of heat or electricity using natural gas instead of coal, for example, can reduce the CO_2 because of the lower carbon content of natural gas. Table 1-6 shows annual changes in emissions during the last six years for coal, petroleum, and natural gas in selected sectors.

Milder weather conditions in summer and winter of 1997 (compared to 1996) moderated the growth of CO_2 emissions from fossil fuel combustion. The shut-down of several nuclear power plants, however, led electric utilities to increase their consumption of coal and other fuels to offset the lost nuclear capacity.

In 1998, warm winter temperatures contributed to a significant drop in residential and commercial natural gas consumption. This drop in emissions from natural gas used for heating was primarily offset by two factors: 1) electric utility emissions, which increased in part due to a hot summer and its associated air conditioning demand; and 2) increased motor gasoline consumption for transportation.

In 1999, the increase in emissions from fossil fuel combustion was driven largely by growth in petroleum consumption for transportation. In addition, residential and commercial heating fuel demand partially recovered as winter temperatures dropped relative to 1998, although temperatures were still warmer than normal.[20] These increases were offset, in part, by a decline in emissions from electric power producers due primarily to: 1) an increase in net generation of electricity by nuclear plants that reduced demand from fossil fuel plants; and 2) moderated summer temperatures compared to the previous year, thereby reducing electricity demand for air conditioning.

Emissions from fuel combustion increased considerably in 2000, due to several factors. The primary reason for the increase was the robust U.S. economy, which produced a high demand for fuels—especially for petroleum in the transportation sector—despite increases in the price of both natural gas and petroleum. Colder winter conditions relative to the previous year triggered a rise in residential and commercial demand for heating. Structural and other economic changes taking place within U.S. industry—especially manufacturing—lead to lower coal consumption. Additionally, electricity generation became more carbon intensive as coal and natural gas consumption offset reduced hydropower output.

In 2001, the U.S. economy slowed for the second time since 1990, resulting in decreased emissions from CO_2 emissions from fossil fuel combustion also for the second time since 1990. A significant reduction in industrial output accompanied this slowdown, primarily in manufacturing, leading to lower emissions from the industrial sector. Several other factors also played a role in this decrease in emissions. Warmer winter conditions compared to 2000, along with higher natural gas prices, reduced demand for heating fuels. Additionally, nuclear facilities operated at their highest capacity on record, replacing electricity produced from fossil fuels. Since there are no greenhouse gas emissions associated with electricity production from nuclear plants, this substitution reduces the carbon intensity of electricity generation.

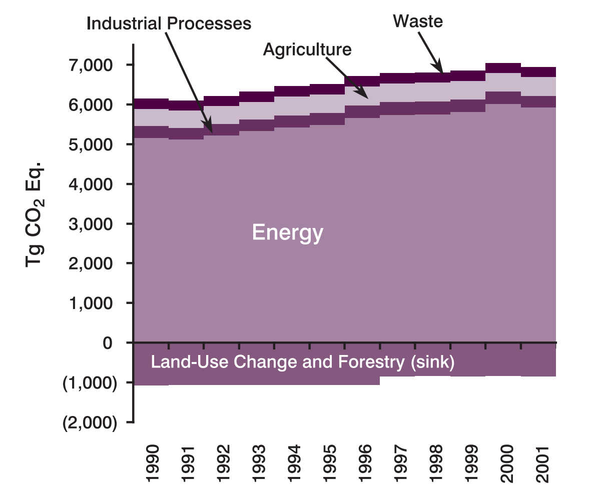
Other significant trends in emissions from additional source categories over the twelve year period from 1990 through 2001 included the following:

[20] Normals are based on data from 1961 through 1990. Source: NOAA (2002)

- Net CO_2 flux from land use change and forestry decreased by 234.7 Tg CO_2 Eq. (22 percent), primarily due to a decline in the rate of net carbon accumulation in forest carbon stocks.
- Aggregate HFC and PFC emissions resulting from the substitution of ozone depleting substances (e.g., CFCs) increased by 62.7 Tg CO_2 Eq. This increase was significantly offset, however, by reductions in PFC emissions from aluminum production (14.0 Tg CO_2 Eq. or 77 percent), reductions in emissions of HFC-23 from the production of HCFC-22 (15.2 Tg CO_2 Eq. or 43 percent), and reductions of SF_6 from electric power transmission and distribution systems (16.8 Tg CO_2 Eq. or 52 percent). Reductions in PFC emissions from aluminum production were the result of both industry emission reduction efforts and lower domestic aluminum production. HFC-23 emissions from the production of HCFC-22 decreased because a reduction in the intensity of emissions from that source offset increased HCFC-22 production. Reduced emissions of SF_6 from electric power transmission and distribution systems are primarily the result of higher purchase prices for SF_6 and efforts by industry to reduce emissions.
- Methane emissions from coal mining dropped by 26.4 Tg CO_2 Eq. (30 percent) as a result of the mining of less gassy coal from underground mines and the increased use of CH_4 collected from degasification systems.
- Nitrous oxide emissions from agricultural soil management increased by 26.8 Tg CO_2 Eq. (10 percent) as fertilizer consumption and cultivation of nitrogen-fixing and other crops rose.
- Carbon dioxide emissions from waste combustion increased 12.8 Tg CO_2 Eq. (91 percent), as the volume of plastics and other fossil carbon-containing materials in municipal solid waste grew.
- By 1998, all of the three major adipic acid producing plants had voluntarily implemented N_2O abatement technology, and as a result, emissions fell by 10.3 Tg CO_2 Eq. (68 percent). The majority of this decline occurred from 1996 collected and combusted by landfill operators has increased.
- Methane emissions from U.S. landfills decreased by 9.1 Tg CO_2 Eq. (4 percent), as the amount of landfill gas collected and combusted by landfill operators has increased.

Figure 1-4

U.S. GHG Emissions by Chapter/IPCC Sector



Overall, from 1990 to 2001, total emissions of CO_2 and N_2O increased by 791.1 (16 percent) and 27.0 Tg CO_2 Eq. (7 percent), respectively, while CH_4 emissions decreased by 38.1 Tg CO_2 Eq. (6 percent). During the same period, aggregate weighted emissions of HFCs, PFCs, and SF_6 rose by 16.6 Tg CO_2 Eq. (18 percent). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, emissions of HFCs, PFCs, and SF_6 are significant because many of them have extremely high global warming potentials and, in the cases of PFCs and SF_6, long atmospheric lifetimes. Conversely, U.S. greenhouse gas emissions were partly offset by carbon sequestration in forests, trees in urban areas, agricultural soils, and landfilled yard trimmings, which was estimated to be 12 percent of total emissions in 2001.

As an alternative, emissions of all gases can be totaled for each of the IPCC sectors. Over the twelve year period of 1990 to 2001, total emissions in the Energy and Agriculture sectors climbed by 779.6 (15 percent) and 33.8 Tg CO_2 Eq. (8 percent), respectively, while emissions from the Industrial Processes and Waste sectors decreased 14.6 Tg CO_2 Eq. (5 percent) and 2.3 Tg CO_2 Eq. (1 percent), respectively. Over the same period, estimates of net carbon sequestration in the Land-Use Change and Forestry sector declined by 234.7 Tg CO_2 Eq. (22 percent).

Table 1-8 summarizes emissions and sinks from all U.S. anthropogenic sources in weighted units of Tg CO_2 Eq., while unweighted gas emissions and sinks in gigagrams (Gg) are provided in Table 1-9. Alternatively, emissions and sinks are aggregated by chapter in Table 1-10 and Figure 1-4.

Table 1-8: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Tg CO_2 Eq.)

Gas/Source	1990	1995	1996	1997	1998	1999	2000	2001
CO_2	**5,003.7**	**5,334.4**	**5,514.8**	**5,595.4**	**5,614.2**	**5,680.7**	**5,883.1**	**5,794.8**
Fossil Fuel Combustion	4,814.8	5,141.5	5,325.8	5,400.0	5,420.5	5,488.8	5,692.2	5,614.9
Iron and Steel Production	85.4	74.4	68.3	71.9	67.4	64.4	65.8	59.1
Cement Manufacture	33.3	36.8	37.1	38.3	39.2	40.0	41.2	41.4
Waste Combustion	14.1	18.5	19.4	21.2	22.5	23.9	25.4	26.9
Ammonia Manufacture & Urea Application	19.3	20.5	20.3	20.7	21.9	20.6	19.6	16.6
Lime Manufacture	11.2	12.8	13.5	13.7	13.9	13.5	13.3	12.9
Natural Gas Flaring	5.5	8.7	8.2	7.6	6.3	6.7	5.5	5.2
Limestone and Dolomite Use	5.5	7.0	7.6	7.1	7.3	7.7	5.8	5.3
Aluminum Production	6.3	5.3	5.6	5.6	5.8	5.9	5.4	4.1
Soda Ash Manufacture and Consumption	4.1	4.3	4.2	4.4	4.3	4.2	4.2	4.1
Titanium Dioxide Production	1.3	1.7	1.7	1.8	1.8	1.9	1.9	1.9
Carbon Dioxide Consumption	0.9	1.1	1.1	1.2	1.2	1.2	1.2	1.3
Ferroalloys	2.0	1.9	2.0	2.0	2.0	2.0	1.7	1.3
Land-Use Change and Forestry (Sink)[a]	(1,072.8)	(1,064.2)	(1,061.0)	(840.6)	(830.5)	(841.1)	(834.6)	(838.1)
International Bunker Fuels[b]	*113.9*	*101.0*	*102.3*	*109.9*	*112.9*	*105.3*	*99.3*	*97.3*
CH_4	**644.0**	**650.0**	**636.8**	**629.5**	**622.7**	**615.5**	**613.4**	**605.9**
Landfills	212.1	216.1	212.1	207.5	202.4	203.7	205.8	202.9
Natural Gas Systems	122.0	127.2	127.4	126.0	124.0	120.3	121.2	117.3
Enteric Fermentation	117.9	123.0	120.5	118.3	116.7	116.6	115.7	114.8
Coal Mining	87.1	73.5	68.4	68.1	67.9	63.7	60.9	60.7
Manure Management	31.3	36.2	34.9	36.6	39.0	38.9	38.2	38.9
Wastewater Treatment	24.1	26.6	26.8	27.3	27.7	28.2	28.3	28.3
Petroleum Systems	27.5	24.2	23.9	23.6	22.9	21.6	21.2	21.2
Rice Cultivation	7.1	7.6	7.0	7.5	7.9	8.3	7.5	7.6
Stationary Sources	8.1	8.5	8.7	7.5	7.2	7.4	7.6	7.4
Mobile Sources	5.0	4.9	4.8	4.7	4.6	4.5	4.4	4.3
Petrochemical Production	1.2	1.5	1.6	1.6	1.6	1.7	1.7	1.5
Field Burning of Agricultural Residues	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8
Silicon Carbide Production	+	+	+	+	+	+	+	+
International Bunker Fuels[b]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**397.6**	**430.9**	**441.7**	**440.9**	**436.8**	**433.0**	**429.9**	**424.6**
Agricultural Soil Management	267.5	284.1	293.2	298.2	299.2	297.0	294.6	294.3
Mobile Sources	50.6	60.9	60.7	60.3	59.7	58.8	57.5	54.8
Manure Management	16.2	16.6	17.0	17.3	17.3	17.4	17.9	18.0
Nitric Acid	17.8	19.9	20.7	21.2	20.9	20.1	19.1	17.6
Human Sewage	12.7	13.9	14.1	14.4	14.6	15.1	15.1	15.3
Stationary Combustion	12.5	13.2	13.8	13.7	13.7	13.7	14.3	14.2
Adipic Acid	15.2	17.2	17.0	10.3	6.0	5.5	6.0	4.9
N_2O Product Usage	4.3	4.5	4.5	4.8	4.8	4.8	4.8	4.8
Field Burning of Agricultural Residues	0.4	0.4	0.4	0.4	0.5	0.4	0.5	0.5
Waste Combustion	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
International Bunker Fuels[b]	*1.0*	*0.9*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*
HFCs, PFCs, and SF_6	**94.4**	**99.5**	**113.6**	**116.8**	**127.6**	**120.3**	**121.0**	**111.0**
Substitution of Ozone Depleting Substances	0.9	21.7	30.4	37.7	44.5	50.9	57.3	63.7
HCFC-22 Production	35.0	27.0	31.1	30.0	40.2	30.4	29.8	19.8
Electrical Transmission and Distribution	32.1	27.5	27.7	25.2	20.9	16.4	15.4	15.3
Semiconductor Manufacture	2.9	5.9	5.4	6.5	7.3	7.7	7.4	5.5
Aluminum Production	18.1	11.8	12.5	11.0	9.0	8.9	7.9	4.1
Magnesium Production and Processing	5.4	5.6	6.5	6.3	5.8	6.0	3.2	2.5
Total	**6,139.6**	**6,514.9**	**6,707.0**	**6,782.6**	**6,801.3**	**6,849.5**	**7,047.4**	**6,936.2**
Net Emissions (Sources and Sinks)	**5,066.8**	**5,450.7**	**5,646.0**	**5,942.0**	**5,970.9**	**6,008.5**	**6,212.7**	**6,098.1**

+ Does not exceed 0.05 Tg CO_2 Eq.
[a] Sinks are only included in net emissions total, and are based partially on projected activity data. Parentheses indicate negative values (or sequestration).
[b] Emissions from International Bunker Fuels are not included in totals.
Note: Totals may not sum due to independent rounding.

Table 1-9: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (Gg)

Gas/Source	1990	1995	1996	1997	1998	1999	2000	2001
CO_2	**5,003,685**	**5,334,446**	**5,514,811**	**5,595,361**	**5,614,198**	**5,680,677**	**5,883,118**	**5,794,804**
Fossil Fuel Combustion	4,814,758	5,141,548	5,325,798	5,400,034	5,420,519	5,488,804	5,692,170	5,614,853
Iron and Steel Production	85,414	74,357	68,324	71,864	67,429	64,376	65,755	59,074
Cement Manufacture	33,278	36,847	37,079	38,323	39,218	39,991	41,190	41,357
Waste Combustion	14,068	18,472	19,418	21,173	22,454	23,903	25,351	26,907
Ammonia Manufacture & Urea Application	19,306	20,453	20,282	20,650	21,934	20,615	19,587	16,588
Lime Manufacture	11,238	12,804	13,495	13,685	13,914	13,466	13,315	12,859
Natural Gas Flaring	5,514	8,729	8,233	7,565	6,250	6,679	5,525	5,179
Limestone and Dolomite Use	5,470	7,042	7,614	7,055	7,331	7,671	5,763	5,281
Aluminum Production	6,315	5,265	5,580	5,621	5,792	5,895	5,410	4,114
Soda Ash Manufacture and Consumption	4,141	4,304	4,239	4,354	4,325	4,217	4,181	4,147
Titanium Dioxide Production	1,308	1,670	1,657	1,836	1,819	1,853	1,918	1,857
Carbon Dioxide Consumption	895	1,088	1,138	1,162	1,186	1,210	1,233	1,257
Ferroalloys	1,980	1,866	1,954	2,038	2,027	1,996	1,719	1,329
Land-Use Change & Forestry (Sink)[a]	(1,072,807)	(1,064,173)	(1,061,016)	(840,622)	(830,477)	(841,054)	(834,637)	(838,137)
International Bunker Fuels[b]	*113,863*	*101,037*	*102,272*	*109,858*	*112,859*	*105,262*	*99,268*	*97,346*
CH_4	**30,667**	**30,954**	**30,324**	**29,977**	**29,652**	**29,311**	**29,207**	**28,851**
Landfills	10,099	10,290	10,100	9,880	9,639	9,701	9,798	9,663
Natural Gas Systems	5,810	6,059	6,069	6,001	5,903	5,728	5,772	5,588
Enteric Fermentation	5,612	5,855	5,737	5,635	5,557	5,551	5,509	5,468
Coal Mining	4,149	3,502	3,255	3,244	3,235	3,033	2,902	2,893
Manure Management	1,490	1,723	1,661	1,741	1,858	1,852	1,820	1,850
Wastewater Treatment	1,147	1,267	1,278	1,301	1,318	1,341	1,348	1,350
Petroleum Systems	1,309	1,153	1,138	1,123	1,090	1,029	1,010	1,011
Rice Cultivation	339	363	332	356	376	395	357	364
Stationary Sources	388	406	415	358	342	351	363	353
Mobile Sources	236	232	227	223	217	214	211	204
Petrochemical Production	56	72	75	77	78	80	79	71
Field Burning of Agricultural Residues	33	31	36	36	37	36	37	36
Silicon Carbide Production	1	1	1	1	1	1	1	+
International Bunker Fuels[b]	*8*	*6*	*6*	*7*	*7*	*6*	*6*	*5*
N_2O	**1,282**	**1,389**	**1,424**	**1,421**	**1,408**	**1,396**	**1,386**	**1,369**
Agricultural Soil Management	863	916	946	962	965	958	950	949
Mobile Sources	163	197	196	195	192	190	185	177
Manure Management	52	53	55	56	56	56	58	58
Nitric Acid	58	64	67	68	67	65	62	57
Human Sewage	41	45	46	46	47	49	49	49
Stationary Combustion	40	43	45	44	44	44	46	46
Adipic Acid	49	56	55	33	19	18	19	16
N_2O Product Usage	14	14	14	15	15	15	15	15
Field Burning of Agricultural Residues	1	1	1	1	1	1	1	1
Waste Combustion	1	1	1	1	1	1	1	1
International Bunker Fuels[b]	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
HFCs, PFCs, and SF_6	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**
Substitution of Ozone Depleting Substances	M	M	M	M	M	M	M	M
HCFC-22 Production[c]	3	2	3	3	3	3	3	2
Electrical Transmission &Distribution[d]	1	1	1	1	1	1	1	1
Semiconductor Manufacture	M	M	M	M	M	M	M	M
Aluminum Production	M	M	M	M	M	M	M	M
Magnesium Production & Processing[d]	+	+	+	+	+	+	+	+
NO_x	**22,860**	**22,434**	**22,149**	**22,284**	**21,963**	**21,199**	**20,555**	**20,048**
CO	**130,575**	**109,149**	**104,063**	**101,132**	**98,976**	**95,464**	**93,965**	**100,653**
NMVOCs	**20,937**	**19,520**	**17,184**	**16,994**	**16,403**	**16,245**	**15,418**	**15,148**

+ Does not exceed 0.5 Gg.
M Mixture of multiple gases
[a] Sinks are not included in CO_2 emissions total, and are based partially on projected activity data.
[b] Emissions from International Bunker Fuels are not included in totals.
[c] HFC-23 emitted
[d] SF_6 emitted
Note: Totals may not sum due to independent rounding.
Note: Parentheses indicate negative values (or sequestration).

Box 1-2: Recent Trends in Various U.S. Greenhouse Gas Emissions-Related Data

Total emissions can be compared with other economic and social indices to highlight changes over time. These comparisons include: 1) emissions per unit of aggregate energy consumption, because energy-related activities are the largest sources of emissions; 2) emissions per unit of fossil fuel consumption, because almost all energy-related emissions involve the combustion of fossil fuels; 3) emissions per unit of electricity consumption, because the electric power industry—utilities and nonutilities combined—was the largest source of U.S. greenhouse gas emissions in 2001; 4) emissions per unit of total gross domestic product as a measure of national economic activity; and 5) emissions per capita.

Table 1-7 provides data on various statistics related to U.S. greenhouse gas emissions normalized to 1990 as a baseline year. Greenhouse gas emissions in the U.S. have grown at an average annual rate of 1.1 percent since 1990. This rate is slower than that for total energy or fossil fuel and much slower than that for either electricity consumption or overall gross domestic product. At the same time, total U.S. greenhouse gas emissions have grown at about the same rate as national population during the last decade (see Figure 1-5). Overall, atmospheric CO_2 concentrations—a function of many complex anthropogenic and natural processes—are increasing at 0.4 percent per year.

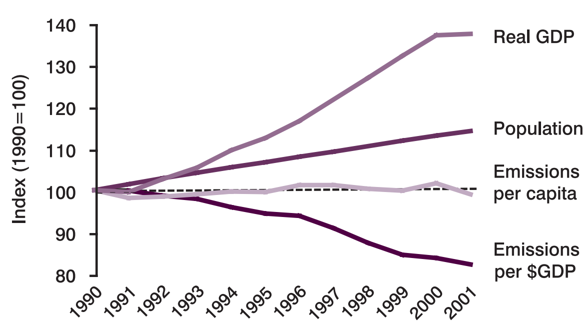
Table 1-7: Recent Trends in Various U.S. Data (Index 1990 = 100)

Variable	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Growth Rate[f]
GHG Emissions[a]	99	101	103	105	106	109	110	111	112	115	113	**1.1%**
Energy Consumption[b]	100	102	104	106	108	112	112	113	115	118	115	**1.3%**
Fossil Fuel Consumption[b]	100	102	104	106	107	111	112	113	114	118	115	**1.3%**
Electricity Consumption[b]	102	102	106	109	112	115	117	121	124	128	127	**2.2%**
GDP[c]	100	103	105	110	112	116	122	127	132	137	137	**2.9%**
Population[d]	101	103	104	105	107	108	109	111	112	113	114	**1.2%**
Atmospheric CO_2 Concentration[e]	100	101	101	101	102	102	103	104	104	104	105	**0.4%**

[a] GWP weighted values
[b] Energy content weighted values (EIA 2002a)
[c] Gross Domestic Product in chained 1996 dollars (BEA 2002)
[d] (U.S. Census Bureau 2002)
[e] Mauna Loa Observatory, Hawaii (Keeling and Whorf 2002)
[f] Average annual growth rate

Figure 1-5

U.S. Greenhouse Gas Emissions Per Capita and Per Dollar of Gross Domestic Product



Source: BEA (2002), U.S. Census Bureau (2002), and emission estimates in this report

Table 1-10: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (Tg CO_2 Eq.)

Chapter/IPCC Sector	1990	1995	1996	1997	1998	1999	2000	2001
Energy	5,147.5	5,481.6	5,661.4	5,733.0	5,749.4	5,809.5	6,010.4	5,927.1
Industrial Processes	302.2	308.2	318.8	321.4	325.9	313.7	312.6	287.6
Agriculture	441.0	468.4	473.7	479.0	481.3	479.3	475.1	474.9
Land-Use Change and Forestry (Sink)*	(1072.8)	(1064.2)	(1061.0)	(840.6)	(830.5)	(841.1)	(834.6)	(838.1)
Waste	248.8	256.6	253.1	249.2	244.7	247.0	249.2	246.6
Total	**6,139.6**	**6,514.9**	**6,707.0**	**6,782.6**	**6,801.3**	**6,849.5**	**7,047.4**	**6,936.2**
Net Emissions (Sources and Sinks)	**5,066.8**	**5,450.7**	**5,646.0**	**5,942.0**	**5,970.9**	**6,008.5**	**6,212.7**	**6,098.1**

* Sinks are only included in net emissions total, and are based partially on projected activity data.
Note: Totals may not sum due to independent rounding.
Note: Parentheses indicate negative values (or sequestration).

Emissions by Economic Sector

Throughout this report, emission estimates are grouped into six sectors (i.e., chapters) defined by the IPCC: Energy, Industrial Processes, Solvent Use, Agriculture, Land-Use Change and Forestry, and Waste. While it is important to use this characterization for consistency with UNFCCC reporting guidelines, it is also useful to allocate emissions into more commonly used sectoral categories. This section reports emissions by the following "economic sectors": Residential, Commercial, Industry, Transportation, Electricity Generation, and Agriculture, and U.S. Territories. Using this categorization, emissions from electricity generation accounted for the largest portion (33 percent) of U.S. greenhouse gas emissions. Transportation activities, in aggregate, accounted for the second largest portion (27 percent). Additional discussion and data on these two economic sectors is provided below.

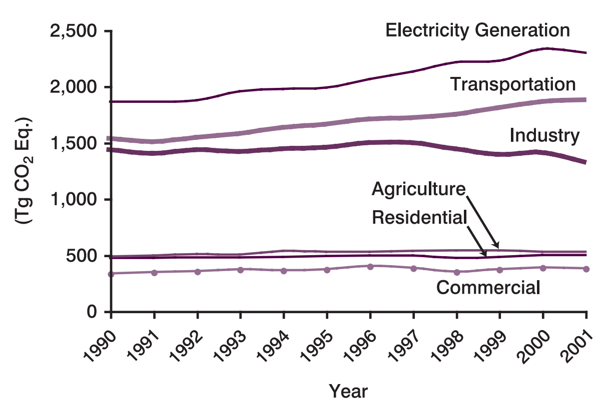
Emissions from industry accounted for 19 percent of U.S. greenhouse gas emissions in 2001. In contrast to electricity generation and transportation, emissions from industry have declined over the past decade, as structural changes have occurred in the U.S. economy (i.e., shifts from a manufacturing base to a service-based economy), fuel switching has occurred, and efficiency improvements have been made. The residential, agriculture, commercial economic sectors, and U.S. territories contributed the remaining 21 percent of emissions. Residences accounted for approximately 5 percent, and primarily consisted of CO_2 emissions from fossil fuel combustion. Activities related to agriculture accounted for roughly 8 percent of U.S. emissions, but unlike all other economic sectors these emissions were dominated by non-CO_2 emissions. The commercial sector accounted for about 7 percent of emissions, while U.S. territories accounted for 1 percent of total emissions.

Carbon dioxide was also emitted and sequestered by a variety of activities related to forest management practices, tree planting in urban areas, the management of agricultural soils, and landfilling of yard trimmings.

Table 1-11 presents a detailed breakdown of emissions from each of these economic sectors by source category, as they are defined in this report. Figure 1-6 shows the trend in emissions by sector from 1990 to 2001.

Figure 1-6

Emissions Allocated to Economic Sectors



Note: Does not include U.S. Territories

Table 1-11: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO_2 Eq. and Percent of Total in 2001)

Sector/Source	1990	1995	1996	1997	1998	1999	2000	2001	Percent[a]
Electricity Generation	**1,862.3**	**1,990.1**	**2,064.1**	**2,130.4**	**2,217.2**	**2,227.5**	**2,331.8**	**2,297.7**	**33.1%**
CO_2 from Fossil Fuel Combustion	1,805.0	1,931.8	2,003.9	2,070.8	2,160.3	2,173.5	2,277.8	2,242.8	32.3%
Waste Combustion[b]	14.4	18.7	19.7	21.4	22.7	24.1	25.6	27.1	0.4%
Transmission & Distribution[c]	32.1	27.5	27.7	25.2	20.9	16.4	15.4	15.3	0.2%
Stationary Combustion[d]	8.1	8.6	9.1	9.3	9.6	9.6	10.0	9.8	0.1%
Limestone and Dolomite Use	2.7	3.5	3.8	3.5	3.7	3.8	2.9	2.6	+
Transportation	**1,525.6**	**1,651.0**	**1,694.1**	**1,706.8**	**1,736.5**	**1,797.7**	**1,849.0**	**1,866.8**	**26.9%**
CO_2 from Fossil Fuel Combustion	1,470.5	1,577.8	1,617.4	1,626.9	1,653.9	1,713.0	1,762.7	1,780.9	25.7%
Mobile Combustion[d]	55.2	65.3	65.0	64.5	63.7	62.7	61.5	58.6	0.8%
Substitution of ODS[e]	+	7.8	11.7	15.4	18.8	21.9	24.8	27.3	0.4%
Industry	**1,423.3**	**1,444.7**	**1,484.9**	**1,485.4**	**1,433.5**	**1,381.4**	**1,400.6**	**1,315.7**	**19.0%**
CO_2 from Fossil Fuel Combustion	909.0	945.7	987.5	992.5	942.5	913.2	940.7	887.2	12.8%
Natural Gas Systems	122.0	127.2	127.4	126.0	124.0	120.3	121.2	117.3	1.7%
Coal Mining	87.1	73.5	68.4	68.1	67.9	63.7	60.9	60.7	0.9%
Iron and Steel Production	85.4	74.4	68.3	71.9	67.4	64.4	65.8	59.1	0.9%
Cement Manufacture	33.3	36.8	37.1	38.3	39.2	40.0	41.2	41.4	0.6%
Petroleum Systems	27.5	24.2	23.9	23.6	22.9	21.6	21.2	21.2	0.3%
HCFC-22 Production[f]	35.0	27.0	31.1	30.0	40.2	30.4	29.8	19.8	0.3%
Nitric Acid	17.8	19.9	20.7	21.2	20.9	20.1	19.1	17.6	0.3%
Ammonia Manufacture	19.3	20.5	20.3	20.7	21.9	20.6	19.6	16.6	0.2%
Lime Manufacture	11.2	12.8	13.5	13.7	13.9	13.5	13.3	12.9	0.2%
Substitution of ODS[e]	+	3.6	6.3	6.6	7.0	7.5	8.0	11.7	0.2%
Aluminum Production[g]	24.4	17.1	18.0	16.6	14.8	14.8	13.3	8.2	0.1%
Stationary Combustion[d]	5.7	6.1	6.3	6.1	6.0	5.8	6.0	6.2	0.1%
Semiconductor Manufacture[e]	2.9	5.9	5.4	6.5	7.3	7.7	7.4	5.5	0.1%
Natural Gas Flaring	5.5	8.7	8.2	7.6	6.3	6.7	5.5	5.2	0.1%
Adipic Acid	15.2	17.2	17.0	10.3	6.0	5.5	6.0	4.9	0.1%
N_2O Product Usage	4.3	4.5	4.5	4.8	4.8	4.8	4.8	4.8	0.1%
Soda Ash Manufacture & Consumption	4.1	4.3	4.2	4.4	4.3	4.2	4.2	4.1	0.1%
Limestone and Dolomite Use	2.7	3.5	3.8	3.5	3.7	3.8	2.9	2.6	+
Magnesium Production & Processing[c]	5.4	5.6	6.5	6.3	5.8	6.0	3.2	2.5	+
Titanium Dioxide Production	1.3	1.7	1.7	1.8	1.8	1.9	1.9	1.9	+
Petrochemical Production	1.2	1.5	1.6	1.6	1.6	1.7	1.7	1.5	+
Ferroalloys	2.0	1.9	2.0	2.0	2.0	2.0	1.7	1.3	+
Carbon Dioxide Consumption	0.9	1.1	1.1	1.2	1.2	1.2	1.2	1.3	+
Silicon Carbide Production	+	+	+	+	+	+	+	+	+
Agriculture	**487.8**	**525.8**	**526.1**	**537.9**	**539.4**	**539.8**	**526.0**	**525.7**	**7.6%**
Agricultural Soil Management	267.5	284.1	293.2	298.2	299.2	297.0	294.6	294.3	4.2%
Enteric Fermentation	117.9	123.0	120.5	118.3	116.7	116.6	115.7	114.8	1.7%
Manure Management[d]	47.5	52.7	51.9	53.8	56.4	56.2	56.1	56.9	0.8%
CO_2 from Fossil Fuel Combustion	46.3	56.9	52.0	58.3	57.6	59.9	50.4	50.4	0.7%
Rice Cultivation	7.1	7.6	7.0	7.5	7.9	8.3	7.5	7.6	0.1%
Field Burning of Agricultural Residues[d]	1.1	1.0	1.2	1.2	1.2	1.2	1.2	1.2	+
Mobile Combustion[d]	0.4	0.5	0.4	0.5	0.5	0.5	0.4	0.4	+
Stationary Combustion[d]	+	+	+	+	+	+	+	+	+
Residential	**334.5**	**371.3**	**402.1**	**385.4**	**352.8**	**372.4**	**390.1**	**379.4**	**5.5%**
CO_2 from Fossil Fuel Combustion	328.9	358.5	388.6	371.7	338.8	357.3	373.9	363.3	5.2%
Substitution of ODS[e]	+	6.9	7.6	9.2	9.8	10.7	11.6	11.6	0.2%
Stationary Combustion[d]	5.7	5.8	5.9	4.5	4.2	4.5	4.6	4.4	0.1%

Continued on next page.

Table 1-11: U.S. Greenhouse Gas Emissions Allocated to Economic Sectors (Tg CO_2 Eq. and Percent of Total in 2001) continued from page 1-16

Sector/Source	1990	1995	1996	1997	1998	1999	2000	2001	Percent[a]
Commercial	**472.4**	**488.0**	**495.5**	**494.0**	**474.2**	**480.6**	**497.6**	**496.5**	**7.2%**
CO_2 from Fossil Fuel Combustion	221.4	226.9	236.4	237.1	219.5	221.7	234.3	235.9	3.4%
Landfills	212.1	216.1	212.1	207.5	202.4	203.7	205.8	202.9	2.9%
Wastewater Treatment	24.1	26.6	26.8	27.3	27.7	28.2	28.3	28.3	0.4%
Human Sewage	12.7	13.9	14.1	14.4	14.6	15.1	15.1	15.3	0.2%
Substitution of ODS[e]	0.9	3.4	4.8	6.5	8.9	10.7	12.8	12.9	0.2%
Stationary Combustion[d]	1.1	1.1	1.2	1.2	1.1	1.1	1.2	1.1	+
U.S. Territories	**33.7**	**44.0**	**40.1**	**42.8**	**47.9**	**50.2**	**52.3**	**54.4**	**0.8%**
CO_2 from Fossil Fuel Combustion	33.7	44.0	40.1	42.8	47.9	50.2	52.3	54.4	0.8%
Total	**6,139.6**	**6,514.9**	**6,707.0**	**6,782.6**	**6,801.3**	**6,849.5**	**7,047.4**	**6,936.2**	**100.0%**
Sinks	**(1,072.8)**	**(1,064.2)**	**(1,061.0)**	**(840.6)**	**(830.5)**	**(841.1)**	**(834.6)**	**(838.1)**	**(12.1%)**
Forests	(982.7)	(979.0)	(979.0)	(759.0)	(751.7)	(762.7)	(755.3)	(759.0)	(10.9%)
Urban Trees	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(58.7)	(0.8%)
Agricultural Soils	(13.3)	(14.9)	(13.6)	(13.9)	(11.5)	(11.9)	(13.8)	(15.2)	(0.2%)
Landfilled Yard Trimmings	(18.2)	(11.6)	(9.7)	(9.0)	(8.7)	(7.8)	(6.9)	(5.3)	(0.1%)
Net Emissions (Sources and Sinks)	**5,066.8**	**5,450.7**	**5,646.0**	**5,942.0**	**5,970.9**	**6,008.5**	**6,212.7**	**6,098.1**	

Note: Includes all emissions of CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6. Parentheses indicate negative values (or sequestration).
Totals may not sum due to independent rounding.
ODS (Ozone Depleting Substances)
+ Does not exceed 0.05 Tg CO_2 Eq. or 0.05%.
- Not applicable.
[a] Percent of total emissions for year 2001.
[b] Includes both CO_2 and N_2O.
[c] SF_6 emitted.
[d] Includes both CH_4 and N_2O.
[e] May includes a mixture of HFCs, PFCs, and SF_6.
[f] HFC-23 emitted.
[g] Includes both CO_2 and PFCs.

Emissions with Electricity Distributed to Economic Sectors

It can also be useful to view greenhouse gas emissions from economic sectors with emissions related to electricity generation distributed into end-use categories (i.e., emissions from electricity generation are allocated to the economic sectors in which the electricity is consumed). The generation, transmission, and distribution of electricity, which is the largest economic sector in the United States, accounted for 33 percent of total U.S. greenhouse gas emissions in 2001. Emissions increased by 23 percent since 1990, as electricity demand grew and fossil fuels remained the dominant energy source for generation. The electricity generation sector in the United States is composed of traditional electric utilities as well as other entities, such as power marketers and nonutility power producers. The majority of electricity generated by these entities was through the combustion of coal in boilers to produce high-pressure steam that is passed through a turbine. Table 1-12 provides a detailed summary of emissions from electricity generation-related activities.

To distribute electricity emissions among economic end-use sectors, emissions from the source categories assigned to the electricity generation sector were allocated to the residential, commercial, industry, transportation, and agriculture economic sectors according to retail sales of electricity (EIA 2002b and Duffield 2002). These three source categories include CO_2 from fossil fuel combustion, CH_4 and N_2O from stationary sources, and SF_6 from electrical transmission and distribution.[21]

[21] Emissions were not distributed to U.S. territories, since the electricity generation sector only includes emissions related to the generation of electricity in the 50 states and the District of Columbia.

Table 1-12: Electricity Generation-Related Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Fuel Type or Source	1990	1995	1996	1997	1998	1999	2000	2001
CO_2	**1,821.8**	**1,953.8**	**2,027.1**	**2,095.5**	**2,186.5**	**2,201.2**	**2,306.1**	**2,272.3**
CO_2 from Fossil Fuel Combustion	1,805.0	1,931.8	2,003.9	2,070.8	2,160.3	2,173.5	2,277.8	2,242.8
Coal	1,530.3	1,643.4	1,734.0	1,778.1	1,808.7	1,817.5	1,906.9	1,856.8
Natural Gas	175.3	228.3	205.0	218.9	248.0	260.1	280.6	284.9
Petroleum	99.0	59.7	64.5	73.5	103.2	95.6	89.9	100.7
Geothermal	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Waste Combustion	14.4	18.7	19.7	21.4	22.7	24.1	25.6	27.1
Limestone and Dolomite Use	2.7	3.5	3.8	3.5	3.7	3.8	2.9	2.6
CH_4	**0.6**	**0.6**	**0.6**	**0.6**	**0.7**	**0.7**	**0.7**	**0.7**
Stationary Combustion*	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7
N_2O	**7.8**	**8.3**	**8.7**	**9.0**	**9.2**	**9.2**	**9.6**	**9.4**
Stationary Combustion*	7.6	8.0	8.5	8.7	8.9	8.9	9.3	9.1
Waste Combustion	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
SF_6	**32.1**	**27.5**	**27.7**	**25.2**	**20.9**	**16.4**	**15.4**	**15.3**
Electrical Transmission and Distribution	32.1	27.5	27.7	25.2	20.9	16.4	15.4	15.3
Total	**1,862.3**	**1,990.1**	**2,064.1**	**2,130.4**	**2,217.2**	**2,227.5**	**2,331.8**	**2,297.7**

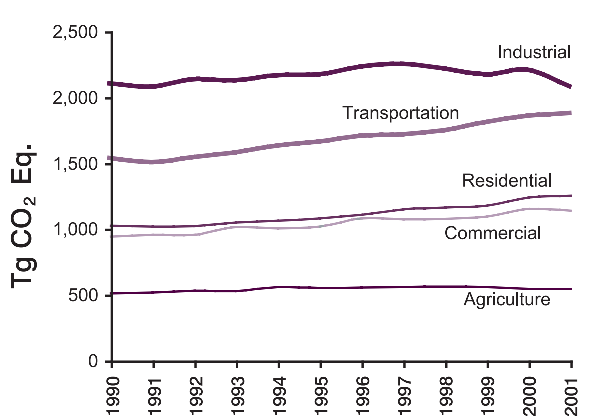
Note: Totals may not sum due to independent rounding.
* Includes only stationary combustion emissions related to the generation of electricity.

When emissions from electricity are distributed among these sectors, industry accounts for the largest share of U.S. greenhouse gas emissions (30 percent). Emissions from the residential and commercial sectors also increase substantially due to their relatively large share of electricity consumption. Transportation activities remain the second largest contributor to emissions. In all sectors except agriculture, CO_2 accounts for more than 75 percent of greenhouse gas emissions, primarily from the combustion of fossil fuels.

Table 1-13 presents a detailed breakdown of emissions from each of these economic sectors, with emissions from electricity generation distributed to them. Figure 1-7 shows the trend in these emissions by sector from 1990 to 2001.

Figure 1-7

Emissions with Electricity Distributed to Economic Sectors



Note: Does not include U.S. Territories

Transportation

Transportation activities accounted for 27 percent of U.S. greenhouse gas emissions in 2001. Table 1-14 provides a detailed summary of greenhouse gas emissions from transportation-related activities. Total emissions in Table 1-14 differ slightly from those shown in Table 1-13 primarily because the table below includes all transportation activities, including those that had been counted under the Agriculture economic sector.

From 1990 to 2001, transportation emissions rose by 22 percent due, in part, to increased demand for travel and the stagnation of fuel efficiency across the U.S. vehicle fleet. Since the 1970s, the number of highway vehicles registered in the United States has increased faster than the overall population, according to the Federal Highway Administration (FHWA). Likewise, the number of miles driven (up 30 percent from 1990 to 2001) and the gallons of

Table 1-13: U.S Greenhouse Gas Emissions by "Economic Sector" and Gas with Electricity-Related Emissions Distributed (Tg CO_2 Eq.) and Percent of Total in 2001

Sector/Gas	1990	1995	1996	1997	1998	1999	2000	2001	Percent[a]
Industry	**2,097.3**	**2,164.0**	**2,224.1**	**2,244.7**	**2,209.4**	**2,165.0**	**2,200.6**	**2,074.0**	**29.9%**
Direct Emissions	1,423.3	1,444.7	1,484.9	1,485.4	1,433.5	1,381.4	1,400.6	1,315.7	19.0%
CO_2	1,081.1	1,116.6	1,153.3	1,163.1	1,110.1	1,077.4	1,103.5	1,037.6	15.0%
CH_4	240.0	229.0	223.8	221.8	218.9	209.6	207.4	203.2	2.9%
N_2O	40.8	45.3	46.0	40.0	35.2	33.9	33.5	31.1	0.4%
HFCs, PFCs, and SF_6	61.3	53.9	61.8	60.5	69.3	60.6	56.3	43.7	0.6%
Electricity-Related	674.0	719.3	739.2	759.3	775.9	783.6	799.9	758.4	10.9%
CO_2	659.3	706.2	725.9	746.9	765.2	774.3	791.1	750.0	10.8%
CH_4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	+
N_2O	2.8	3.0	3.1	3.2	3.2	3.2	3.3	3.1	+
SF_6	11.6	9.9	9.9	9.0	7.3	5.8	5.3	5.1	0.1%
Transportation	**1,528.8**	**1,654.1**	**1,697.2**	**1,710.0**	**1,739.6**	**1,800.9**	**1,852.4**	**1,870.5**	**27.0%**
Direct Emissions	1,525.6	1,651.0	1,694.1	1,706.8	1,736.5	1,797.7	1,849.0	1,866.8	26.9%
CO_2	1,470.5	1,577.8	1,617.4	1,626.9	1,653.9	1,713.0	1,762.7	1,780.9	25.7%
CH_4	4.5	4.4	4.3	4.2	4.1	4.0	4.0	3.9	0.1%
N_2O	50.6	60.9	60.7	60.3	59.7	58.8	57.46	54.75	0.8%
HFCs[b]	+	7.8	11.7	15.4	18.8	21.9	24.78	27.35	0.4%
Electricity-Related	3.1	3.1	3.1	3.1	3.2	3.2	3.45	3.62	0.1%
CO_2	3.1	3.0	3.0	3.1	3.1	3.2	3.4	3.6	0.1%
CH_4	+	+	+	+	+	+	+	+	+
N_2O	+	+	+	+	+	+	+	+	+
SF_6	0.1	+	+	+	+	+	+	+	+
Residential	**943.2**	**1,019.5**	**1,080.5**	**1,073.8**	**1,076.2**	**1,095.5**	**1,154.7**	**1,138.7**	**16.4%**
Direct Emissions	334.5	371.3	402.1	385.4	352.8	372.4	390.1	379.4	5.5%
CO_2	328.9	358.5	388.6	371.7	338.8	357.3	373.9	363.3	5.2%
CH_4	4.6	4.7	4.7	3.6	3.3	3.5	3.7	3.5	0.1%
N_2O	1.1	1.2	1.2	1.0	0.9	0.9	1.0	0.9	+
HFCs	+	6.9	7.6	9.2	9.8	10.7	11.6	11.6	0.2%
Electricity-Related	608.7	648.3	678.4	688.4	723.4	723.1	764.5	759.3	10.9%
CO_2	595.4	636.4	666.3	677.2	713.4	714.5	756.1	750.9	10.8%
CH_4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	+
N_2O	2.6	2.7	2.9	2.9	3.0	3.0	3.1	3.1	+
SF_6	10.5	9.0	9.1	8.2	6.8	5.3	5.1	5.1	0.1%
Commercial	**1,024.5**	**1,080.7**	**1,109.7**	**1,150.9**	**1,164.2**	**1,177.7**	**1,240.9**	**1,252.6**	**18.1%**
Direct Emissions	472.4	488.0	495.5	494.0	474.2	480.6	497.6	496.5	7.2%
CO_2	221.4	226.9	236.4	237.1	219.5	221.7	234.3	235.9	3.4%
CH_4	236.9	243.5	239.8	235.7	230.9	232.7	234.9	232.1	3.3%
N_2O	13.1	14.3	14.5	14.8	15.0	15.4	15.5	15.6	0.2%
HFCs	0.9	3.4	4.8	6.5	8.9	10.7	12.8	12.9	0.2%
Electricity-Related	552.2	592.7	614.2	656.9	690.0	697.1	743.3	756.1	10.9%
CO_2	540.2	581.8	603.2	646.2	680.5	688.9	735.1	747.8	10.8%
CH_4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	+
N_2O	2.3	2.5	2.6	2.8	2.8	2.9	3.1	3.1	+
SF_6	9.5	8.2	8.2	7.8	6.5	5.1	4.9	5.0	0.1%
Agriculture	**512.1**	**552.6**	**555.3**	**560.4**	**564.0**	**560.3**	**546.5**	**546.0**	**7.9%**
Direct Emissions	487.8	525.8	526.1	537.9	539.4	539.8	526.0	525.7	7.6%
CO_2	46.3	56.9	52.0	58.3	57.6	59.9	50.4	50.4	0.7%
CH_4	157.1	167.6	163.2	163.3	164.6	164.7	162.3	162.2	2.3%
N_2O	284.4	301.4	310.9	316.3	317.3	315.2	313.3	313.1	4.5%
Electricity-Related	24.3	26.8	29.2	22.5	24.6	20.5	20.5	20.3	0.3%
CO_2	23.8	26.3	28.7	22.2	24.2	20.3	20.3	20.0	0.3%
CH_4	+	+	+	+	+	+	+	+	+
N_2O	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	+
SF_6	0.4	0.4	0.4	0.3	0.2	0.2	0.1	0.1	+
U.S. Territories	**33.7**	**44.0**	**40.1**	**42.8**	**47.9**	**50.2**	**52.3**	**54.4**	**0.8%**
CO_2	33.7	44.0	40.1	42.8	47.9	50.2	52.3	54.4	0.3%
Total	**6,139.6**	**6,514.9**	**6,707.0**	**6,782.6**	**6,801.3**	**6,849.5**	**7,047.4**	**6,936.2**	**-**

Note: Emissions from electricity generation are allocated based on aggregate electricity consumption in each end-use sector.
Totals may not sum due to independent rounding.
\+ Does not exceed 0.05 Tg CO_2 Eq. or 0.05 percent.
[a] Percents for year 2001.
[b] Includes primarily HFC-134a.

Table 1-14: Transportation-Related Greenhouse Gas Emissions (Tg CO_2 Eq.)

Gas/Vehicle Type	1990	1995	1996	1997	1998	1999	2000	2001
CO_2	**1,473.5**	**1,580.9**	**1,620.4**	**1,630.0**	**1,657.0**	**1,716.2**	**1,766.1**	**1,784.4**
Passenger Cars	600.3	587.2	594.3	592.8	607.9	618.6	621.7	632.7
Light-Duty Trucks	306.2	392.9	406.5	419.1	427.6	446.1	450.2	460.0
Other Trucks	203.9	237.0	246.5	257.6	269.3	284.2	294.7	298.3
Buses	7.5	7.9	8.2	8.3	8.6	9.6	9.3	8.6
Alternative Fuel Vehicles	1.3	1.2	1.1	1.1	1.3	1.1	1.3	1.2
Aircraft[a]	176.9	171.4	180.2	179.0	183.0	186.8	195.3	183.9
Boats and Vessels	48.6	51.7	48.1	33.6	27.4	38.6	59.7	58.3
Locomotives	28.1	30.8	31.8	31.6	32.4	34.1	33.8	34.3
Other[b]	100.7	100.7	103.8	107.0	99.5	97.1	100.2	107.2
International Bunker Fuels[c]	*113.9*	*101.0*	*102.3*	*109.9*	*112.9*	*105.3*	*99.3*	*97.3*
CH_4	**5.0**	**4.9**	**4.8**	**4.7**	**4.6**	**4.5**	**4.4**	**4.3**
Passenger Cars	2.4	2.0	2.0	2.0	2.0	1.9	1.9	1.8
Light-Duty Trucks	1.6	1.9	1.8	1.7	1.7	1.6	1.5	1.5
Other Trucks and Buses	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Alternative Fuel Vehicles	+	+	0.1	0.1	0.1	0.1	0.1	0.1
Aircraft	0.2	0.1	0.1	0.2	0.1	0.2	0.2	0.1
Boats	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Locomotives	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Other[d]	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
International Bunker Fuels[c]	*0.2*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*
N_2O	**50.6**	**60.9**	**60.7**	**60.3**	**59.7**	**58.8**	**57.5**	**54.8**
Passenger Cars	31.0	33.4	33.1	32.6	32.2	31.2	30.2	28.7
Light-Duty Trucks	14.1	21.1	21.1	21.1	20.6	20.4	19.9	18.9
Other Trucks and Buses	2.5	3.2	3.4	3.6	3.7	3.8	3.8	3.8
Alternative Fuel Vehicles	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Aircraft	1.7	1.7	1.8	1.7	1.8	1.8	1.9	1.8
Boats	0.4	0.5	0.4	0.3	0.3	0.4	0.5	0.3
Locomotives	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Other[d]	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.7
International Bunker Fuels[c]	*1.0*	*0.9*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*
HFCs	**+**	**7.8**	**11.7**	**15.4**	**18.8**	**21.9**	**24.8**	**27.3**
Mobile Air Conditioners[e]	+	6.7	9.8	12.9	15.7	18.2	20.4	22.5
Refrigerated Transport	+	1.2	1.9	2.5	3.2	3.8	4.4	4.9
Total	**1,529.1**	**1,654.5**	**1,697.6**	**1,710.4**	**1,740.1**	**1,801.4**	**1,852.8**	**1,870.8**

\+ Does not exceed 0.05 Tg CO_2 Eq.
Note: Totals may not sum due to independent rounding.
[a] Aircraft emissions consist of emissions from all jet fuel (less bunker fuels) and aviation gas consumption.
[b] "Other" CO_2 emissions include motorcycles, construction equipment, agricultural machinery, pipelines, and lubricants.
[c] Emissions from International Bunker Fuels include emissions from both civilian and military activities, but are not included in totals.
[d] "Other" CH_4 and N_2O emissions include motorcycles, construction equipment, agricultural machinery, industrial equipment, and snowmobiles.
[e] Includes primarily HFC-134a.

gasoline consumed each year in the United States have increased steadily since the 1980s, according to the FHWA and Energy Information Administration, respectively. These increases in motor vehicle usage are the result of a confluence of factors including population growth, economic growth, urban sprawl, low fuel prices, and increasing popularity of sport utility vehicles and other light-duty trucks that tend to have lower fuel efficiency. A similar set of social and economic trends has led to a significant increase in air travel and freight transportation by both air and road modes during the 1990s.

Almost all of the energy consumed for transportation was supplied by petroleum-based products, with nearly two-thirds being related to gasoline consumption in automobiles and other highway vehicles. Other fuel uses, especially diesel fuel for freight trucks and jet fuel for aircraft, accounted for the remainder. The primary driver of transportation-related emissions was CO_2 from fossil fuel combustion, which increased by 21 percent from 1990 to 2001. This rise in CO_2 emissions, combined with increases of 27.3 Tg CO_2 Eq. and 4.2 Tg CO_2 Eq. in HFC and N_2O emissions over the same period, led to an increase in overall emissions from transportation activities of 22 percent.

Methodology and Data Sources

Emissions of greenhouse gases from various source and sink categories have been estimated using methodologies that are consistent with the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997). To the extent possible, the present report relies on published activity and emission factor data. Depending on the emission source category, activity data can include fuel consumption or deliveries, vehicle-miles traveled, raw material processed, etc. Emission factors are factors that relate quantities of emissions to an activity. For some sources, IPCC default methodologies and emission factors have been employed. However, for most emission sources, the IPCC methodologies were expanded and more comprehensive methods were applied.

Inventory emission estimates from energy consumption and production activities are based primarily on the latest official fuel consumption data from the Energy Information Administration (EIA) of the U.S. Department of Energy and augmented with additional data where available. Emission estimates for NO_x, CO, and NMVOCs were taken directly, except where noted, from EPA data published on the National Emission Inventory (NEI) Air Pollutant Emission Trends web site (EPA 2003), which provides the latest estimates of regional and national emissions of local air pollutants. Emissions of these pollutants are estimated by the EPA based on statistical information about each source category, emission factors, and control efficiencies. While the EPA's estimation methodologies for local air pollutants are conceptually similar to the IPCC recommended methodologies, the large number of sources EPA used in developing its local air pollutant estimates makes it difficult to reproduce the methodologies from EPA (2003) in this inventory document. In these instances, the references containing detailed documentation of the methods used are identified for the interested reader. For agricultural sources, the EPA local air pollutant emission estimates were supplemented using activity data from other agencies. Complete documentation of the methodologies and data sources used is provided in conjunction with the discussion of each source and in the various annexes.

Emissions from fossil fuels combusted in civilian and military ships and aircraft engaged in the international transport of passengers and cargo are not included in U.S. totals, but are reported separately as international bunkers in accordance with IPCC reporting guidelines (IPCC/UNEP/OECD/IEA 1997). Carbon dioxide emissions from fuel combusted within U.S. territories, however, are included in U.S. totals.

Box 1-3: IPCC Good Practice Guidance

In response to a request by Parties to the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC) prepared and published a report on inventory good practice. The report, entitled *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (Good Practice),* was developed with extensive participation of experts from the United States and many other countries.[22] It focuses on providing direction to countries to produce emission estimates that are as accurate and transparent as possible, with the least possible uncertainty. In addition, G*ood Practice* was designed as a tool to complement the methodologies suggested in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC Guidelines)*.

In order to obtain these goals, *Good Practice* gives specific guidance in the following areas:

- Selection of the most appropriate estimation method, within the context of the *IPCC Guidelines*
- Implementation of quality control and quality assurance measures
- Proper assessment and documentation of data and information
- Quantification of uncertainties for each source category

By providing such direction, the IPCC hopes to help countries provide inventories that are transparent, documented, and comparable.

[22] See <http://www.ipcc-nggip.iges.or.jp/public/gp/gpgaum.htm>

In order to aggregate emissions by economic sector, source category emission estimates were generated according to the methodologies outlined in the appropriate sections of this report. Those emissions, then, were simply reallocated into economic sectors. In most cases, the IPCC subcategories distinctly fit into an apparent economic sector category. Several exceptions exist, and the methodologies used to disaggregate these subcategories are described below:

- *Agricultural CO_2 Emissions from Fossil Fuel Combustion, and non-CO_2 emissions from Stationary and Mobile Combustion.* Emissions from on-farm energy use were accounted for in the Energy chapter as part of the industrial and transportation end-use sectors. To calculate agricultural emissions related to fossil fuel combustion, energy consumption estimates were obtained from economic survey data from the U.S. Department of Agriculture (Duffield 2002) and fuel sales data (EIA 1991 through 2002). To avoid double counting, emission estimates of CO_2 from fossil fuel combustion and non-CO_2 from stationary and mobile sources were subtracted from the industrial economic sector, although some of these fuels may have been originally accounted for under the transportation end-use sector.
- *Landfills, Wastewater Treatment and Human Sewage.* CH_4 emissions from landfills and wastewater treatment, as well as N_2O emissions from human sewage, were allocated to the commercial sector.
- *Waste Combustion.* CO_2 and N_2O emissions from waste combustion were allocated completely to the electricity generation sector since nearly all-waste combustion occurs in waste-to-energy facilities.
- *Limestone and Dolomite Use.* CO_2 emissions from limestone and dolomite use are allocated to the electricity generation (50 percent) and industrial (50 percent) sectors, because 50 percent of the total emissions for this source are used in flue gas desulfurization.
- *Substitution of Ozone Depleting Substances.* All greenhouse gas emissions resulting from the substitution of ozone depleting substances were placed in the industrial economic sector, with the exception of emissions from domestic, commercial, mobile and transport refrigeration/air-conditioning systems were placed in the residential, commercial, and transportation sectors, respectively. Emissions from non-MDI aerosols were attributed to the residential economic sector.

The UNFCCC reporting guidelines requires countries to complete a "top-down" Reference Approach for estimating CO_2 emissions from fossil fuel combustion in addition to their "bottom-up" sectoral methodology. This estimation sources than those contained in that section of the Energy chapter. This reference method estimates fossil fuel consumption by adjusting national aggregate fuel production data for imports, exports, and stock changes rather than relying on end-user consumption surveys (see Annex W). The reference approach assumes that once carbon-based fuels are brought into a national economy they are either saved in some way (e.g., stored in products, kept in fuel stocks, or left unoxidized in ash) or combusted, and therefore the carbon in them is oxidized and released into the atmosphere. Accounting for actual consumption of fuels at the sectoral or sub-national level is not required.

Uncertainty in and Limitations of Emission Estimates

While the current U.S. emissions inventory provides a solid foundation for the development of a more detailed and comprehensive national inventory, it has uncertainties associated with the emission estimates. Some of the current estimates, such as those for CO_2 emissions from energy-related activities and cement processing, are considered to be highly accurate. For some other categories of emissions, however, a lack of data or an incomplete understanding of how emissions are generated limits the scope or accuracy of the estimates presented. Despite these uncertainties, the UNFCCC reporting guidelines follow the recommendation in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and require that countries provide single point estimates for each gas and emission or removal source category. Within the discussion of each emission source, specific factors affecting the accuracy of the estimates are discussed.

While the IPCC methodologies provided in the *Revised 1996 IPCC Guidelines* represent baseline methodologies for a variety of source categories, many of these methodologies continue to be improved and refined as new research and data becomes available. This report uses the IPCC methodologies when applicable, and supplements them with other available methodologies and data where possible. The United States realizes that additional efforts are still needed to improve methodologies and data collection procedures. Specific areas requiring further research include:

- *Incorporating excluded emission sources.* Quantitative estimates of some of the sources and sinks of greenhouse gas emissions are not available at this time. In particular, emissions from some land-use activities and industrial processes are not included in the inventory either because data are incomplete or because methodologies do not exist for estimating emissions from these source categories. See Annex X for a discussion of the sources of greenhouse gas emissions and sinks excluded from this report.
- *Improving the accuracy of emission factors.* Further research is needed in some cases to improve the accuracy of emission factors used to calculate emissions from a variety of sources. For example, the accuracy of current emission factors applied to CH_4 and N_2O emissions from stationary and mobile combustion is highly uncertain.
- *Collecting detailed activity data.* Although methodologies exist for estimating emissions for some sources, problems arise in obtaining activity data at a level of detail in which aggregate emission factors can be applied. For example, the ability to estimate emissions of SF_6 from electrical transmission and distribution is limited due to a lack of activity data regarding national SF_6 consumption or average equipment leak rates.

Emissions calculated for the U.S. inventory reflect current best estimates; in some cases, however, estimates are based on approximate methodologies, assumptions, and incomplete data. As new information becomes available in the future, the United States will continue to improve and revise its emission estimates.

Organization of Report

In accordance with the IPCC guidelines for reporting contained in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997), this Inventory of U.S. Greenhouse Gas Emissions and Sinks is segregated into six sector-specific chapters, listed below in Table 1-15.

Table 1-15: IPCC Sector Descriptions

Chapter/IPCC Sector	Activities Included
Energy	Emissions of all greenhouse gases resulting from stationary and mobile energy activities including fuel combustion and fugitive fuel emissions.
Industrial Processes	By-product or fugitive emissions of greenhouse gases from industrial processes not directly related to energy activities such as fossil fuel combustion.
Solvent Use	Emissions, of primarily non-methane volatile organic compounds (NMVOCs), resulting from the use of solvents.
Agriculture	Anthropogenic emissions from agricultural activities except fuel combustion and sewage emissions, which are addressed under Energy and Waste, respectively.
Land-Use Change and Forestry	Emissions and removals of CO_2 from forest management, other land-use activities, and land-use change.
Waste	Emissions from waste management activities.

Source: (IPCC/UNEP/OECD/IEA 1997)

Within each chapter, emissions are identified by the anthropogenic activity that is the source or sink of the greenhouse gas emissions being estimated (e.g., coal mining). Overall, the following organizational structure is consistently applied throughout this report:

Chapter/IPCC Sector:
Overview of emission trends for each IPCC defined sector.

Source Category:
Description of source pathway and emission trends.

Methodology:
Description of analytical methods employed to produce emission estimates.

Data Sources:
Identification of data references, primarily for activity data and emission factors.

Uncertainty:
Discussion of relevant issues related to the uncertainty in the emission estimates presented.

Special attention is given to CO_2 from fossil fuel combustion relative to other sources because of its share of emissions relative to other sources and its dominant influence on emission trends. For example, each energy consuming end-use sector (i.e., residential, commercial, industrial, and transportation), as well as the electricity generation sector, are treated individually. Additional information for certain source categories and other topics is also provided in several Annexes listed in Table 1-16.

Table 1-16: List of Annexes

ANNEX A	Methodology for Estimating Emissions of CO_2 from Fossil Fuel Combustion
ANNEX B	Methodology for Estimating the Carbon Content of Fossil Fuels
ANNEX C	Methodology for Estimating Carbon Stored in Products from Non-Energy Uses of Fossil Fuels
ANNEX D	Methodology for Estimating Emissions of CH_4, N_2O, and Ambient Air Pollutants from Stationary Combustion
ANNEX E	Methodology for Estimating Emissions of CH_4, N_2O, and Ambient Air Pollutants from Mobile Combustion and Methodology for and Supplemental Information on Transportation-Related GHG Emissions
ANNEX F	Methodology for Estimating CH_4 Emissions from Coal Mining
ANNEX G	Methodology for Estimating CH_4 Emissions from Natural Gas Systems
ANNEX H	Methodology for Estimating CH_4 Emissions from Petroleum Systems
ANNEX I	Methodology for Estimating CO_2 Emissions from Municipal Solid Waste Combustion
ANNEX J	Methodology for Estimating Emissions from International Bunker Fuels used by the U.S. Military
ANNEX K	Methodology for Estimating HFC and PFC Emissions from Substitution of Ozone Depleting Substances
ANNEX L	Methodology for Estimating CH_4 Emissions from Enteric Fermentation
ANNEX M	Methodology for Estimating CH_4 and N_2O Emissions from Manure Management
ANNEX N	Methodology for Estimating N_2O Emissions from Agricultural Soil Management
ANNEX O	Methodology for Estimating Net Changes in Forest Carbon Stocks
ANNEX P	Methodology for Estimating Net Changes in Carbon Stocks in Mineral and Organic Soils
ANNEX Q	Methodology for Estimating CH_4 Emissions from Landfills
ANNEX R	Key Source Analysis
ANNEX S	Global Warming Potential Values
ANNEX T	Ozone Depleting Substance Emissions
ANNEX U	Sulfur Dioxide Emissions
ANNEX V	Complete List of Source Categories
ANNEX W	IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion
ANNEX X	Sources of Greenhouse Gas Emissions Excluded
ANNEX Y	Constants, Units, and Conversions
ANNEX Z	Abbreviations
ANNEX AA	Chemical Formulas
ANNEX AB	Glossary